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THE PREVALENCE OF SPECTACLE WEAR AND INCIDENCE OF REFRACTIVE ERROR IN USAF AIRCREW

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The Prevalence of Spectacle Wear and Incidence of Refractive Error in USAF Aircrew

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

A retrospective survey of 6,500 active aircrew records was performed at 12 U.S. Air Force bases to determine the prevalance of spectacle wear and the incidence of refractive error. The data revealed that 27.4% of pilots, 51.5% of navigators/weapons systems operators, and 40.2% of other aircrew members were required to wear spectacles when flying. Of those pilots who wear spectacles, 12.4% require bifocals. The refractive data showed that myopia was the predominant refractive error, and that relatively large percentages of aircrew members had astigmatism of 0.75 diopters or more; e.g., 33.1% of pilots. Refractive data at the time of entry into the U.S. Air Force was clustered around emmetropia with a definite skew toward hyperopia.

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THE PREVALENCE OF SPECTACLE WEAR AND INCIDENCE OF REFRACTIVE ERROR IN USAF AIRCREW

INTRODUCTION

Statistical data on the number of United States Air Force (USAF) aircrew members required to wear spectacles when flying is very important. Cockpit environments in today's high-performance aircraft are often incompatible with spectacle-wearing aircrew. Thus, if the number of spectacle wearers becomes large, human factors design changes must be considered to provide for spectacle integration with life-support equipment. Spectacle-wearing flyers have proven that they can perform the mission (2,3,10), but they do experience problems with reduced field of vision, discomfort, frame displacement from G-forces, lens fogging, and reflections at night. In addition, integrating spectacles with chemical defense equipment, night vision goggles, helmet-mounted sights, and laser/flash blindness protection poses significant problems. Solutions to these problems include designing equipment to be compatible with spectacles, designing a new aircrew spectacle frame to be compatible with equipment, or fitting contact lenses in lieu of spectacles. Clearly, the recent interest in contact lens wear by aircrew members attests to the inherent problems with spectacle wear in flight.

In 1980, Provines et al. (11) conducted a survey which revealed that 20% of USAF pilots and 50% of USAF navigators were required to wear spectacles in the cockpit to correct their distance vision. Since then, the visual standards for aircrew selection have changed. To update this data, we initiated a study at the USAF School of Aerospace Medicine (USAFSAM/NGO) to define the prevalence of spectacle wear and incidence of refractive error among USAF flyers. The data was collected by a team of vision scientists and optometric technicians who screened over 6,500 flight medical records of pilots, navigators/weapons system operators, and other aircrew members (the last category included flight surgeons, nonrated flight officers, and enlisted personnel).

METHOD

A survey of flight medical records was performed at 12 USAF bases within 4 major commands (MAJCOMs). The MAJCOMs selected were Air Training Command (ATC), Tactical Air Command (TAC), Strategic Air Command (SAC), and Military Airlift Command (MAC). These MAJCOMs contain 72% of all USAF pilots and navigators. Only USAF bases which could provide a representative sample from each MAJCOM were selected for the study. The bases chosen were Beale, Bergstrom, Cannon, Carswell, Davis-Monthan, Eaker, Little Rock, Luke, Mather, Randolph, Travis, and Williams. These bases provided sample sizes sufficiently large to meet the desired criteria for pilots of 95% confidence that the sample data

were within 5% of the population data. The formulas used were from Cochran* for sampling from finite populations with variances conservatively estimated by assuming p = 0.5.

A team consisting of four optometrists, one ophthalmologist, and five optometry technicians collected the data. At least two team members, one of whom was a vision specialist, reviewed the records at each base. The data was manually transcribed on paper and subsequently entered into a computer. To simplify the complex task of retrieving refraction information from individual flight medical records, each team member was thoroughly trained to collect data using standardized methods.

Only the records of active flyers (A flying status codes) were reviewed; flying personnel in nonflying staff jobs (J flying status codes) were not included. Data were collected on three categories of aviators: pilots, navigators and/or weapons system operators, and all other aircrew members. These categories were labeled Pilots, Nav/WSO, and Others for data analysis.

The USAFSAM/NGO team transcribed refractive data from the medical records of pilots and Nav/WSO at three milestones: entry on extended active duty (EAD) in the Air Force, entry into undergraduate pilot or navigator training (UPT or UNT), and most current annual examination. Only current refractive data were recorded for the Others category. Additional recorded information included uncorrected visual acuity, age, bifocal wear, and entry mode into the Air Force [USAF Academy (USAFA), USAF Reserve Officer Training Corps (ROTC), Officer Training School (OTS), etc.]. It should be noted that, because of the vast amount of information recorded, some data were inadvertently lost during the data entry and transcription process. Therefore, the number of subjects may vary slightly at each milestone.

RESULTS

Prevalence of Spectacle Wear

The prevalence of spectacle wear data is displayed in Table 1, which lists the percentages of aircrew members required to wear spectacles, by flying category and MAJCOM. The overall percentages, which included both single vision and bifocal wearers, were as follows: Pilots, 27.4%; Nav/WSO, 51.5%; Others, 40.2%. Of those aircrew members required to wear spectacles, 12.4% of pilots, 2.4% of Nav/WSO, and 3.8% of other aircrew members were prescribed bifocals. Of the pilots sampled who wear bifocals, 72 out of 110 (65%) also required spectacle correction for distance vision.

Visual Acuity

Uncorrected visual acuities for pilots and navigators are shown in Figure 1. Most pilots (79.8%) and over one-half of navigators (54.9%) had 20/20 or better

*William G. Cochran, "Sampling Techniques - 2nd Edition," John Wiley & Sons, Inc., New York, 1963, pp. 74-75.

uncorrected visual acuity (Table A-1). Compared to pilots, there were more Nav/WSO who had reduced visual acuity, especially in the 20/100 or worse category.

TABLE 1. AIRCREW MEMBERS REQUIRING SPECTACLES

MAJCOM	Pilots	Nav/WSO	Others
ATC	25.8%	51.1%	56.2%
MAC	25.9%	49.2%	36.1%
SAC	29.2%	51.3%	41.0%
TAC	30.2%	54.8%	53.9%
Total	27.4%	51.5%	40.2%
N	3226	1634	1596

N = Total number of aircrew members surveyed.

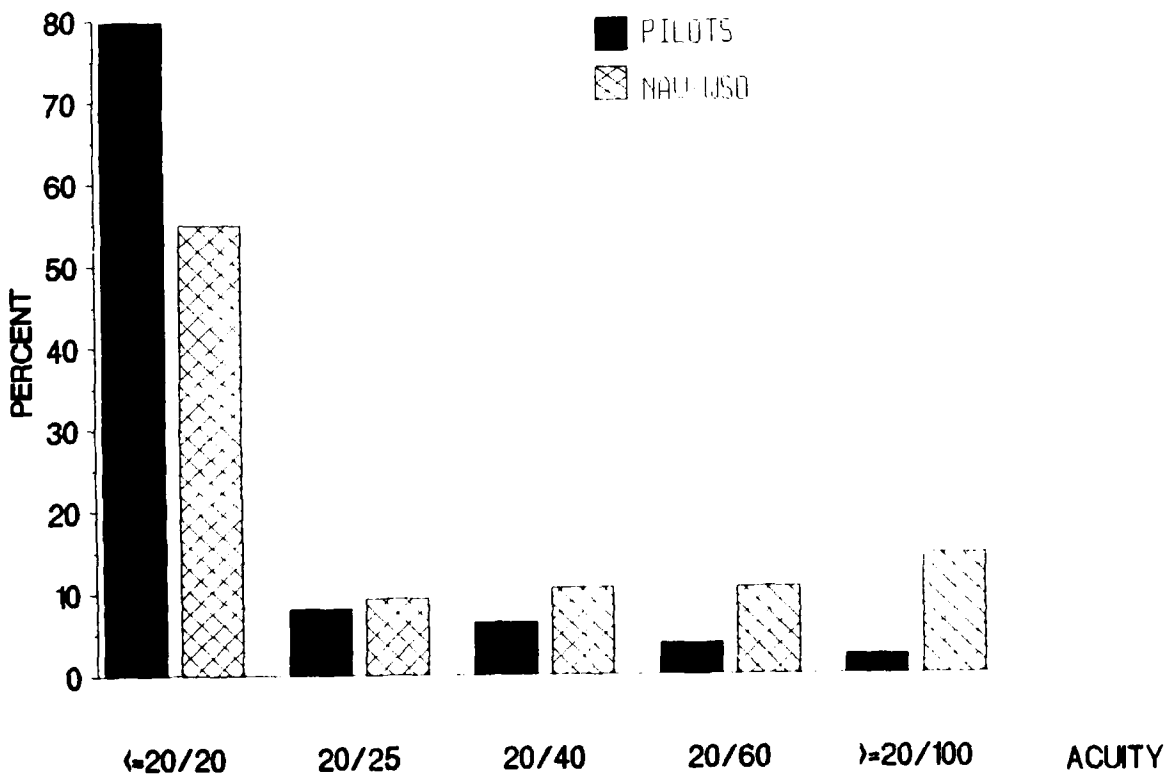

Figure 1. Distribution, as percent of the total, for uncorrected visual acuity in pilots (N=3226) and Nav/WSO (N=1634). (Also see Table A-1.)

Statistical Validity

The current aircrew population for each MAJCOM is listed in Table 2, along with the respective sample sizes from our study. The total Air Force-wide population for each aircrew category appears at the bottom of the table. Except for those marked with an asterisk, the sample sizes were sufficient to satisfy the criteria of 95% confidence that the population data does not differ from our sample data by more than 5%. The asterisk-marked (*) sample sizes have a ±7% accuracy with 95% confidence. Data on student pilots and navigators were included in ATC, which explains why the sample size for ATC navigators is larger than the active flying population.

TABLE 2. POPULATIONS AND SAMPLE SIZES BY FLYING CATEGORY

MAJCOM	Pilots			Nav/WSO			Other		
	P	S	%	P	S	%	P	S	%
ATC	3430	1298	37.8	652	765	117.0	201	48	23.9*
MAC	5438	619	11.4	1513	177	11.7*	5774	947	16.4
SAC	4527	525	11.6	4041	433	10.7	1737	402	23.1
TAC	5052	784	15.5	1453	259	17.8*	1576	204	12.9*
Total	18,447	3226	17.5	7659	1634	21.3	9288	1596	17.2
USAF totals		25,603			10,583			11,930	

P = population
S = sample size
* = ±7% accuracy with 95% confidence

Age

The distribution (frequency percentages) of age for pilots and Nav/WSO in our sample is shown in Figure 2. The age data of all four MAJCOMs were combined. The mean ages in years for the three aircrew categories were as follows: Pilots - 31, Nav/WSO - 29, and Others - 30. The data ranged from 21 to 55 years of age. Individuals 40 years of age or older comprised 16.5% of the pilots and 7.1% of the Nav/WSO. On average, the overall time in service for Pilots was 10 years, for Nav/WSO, 7 years, and for Others, 9 years.

The age distribution of the total USAF population of actively flying pilots and Nav/WSO is displayed in Figure 3 for direct comparison with our sample data. The sample data are somewhat skewed to the left because, unlike the population data, some student pilots and Nav/WSO were included. After

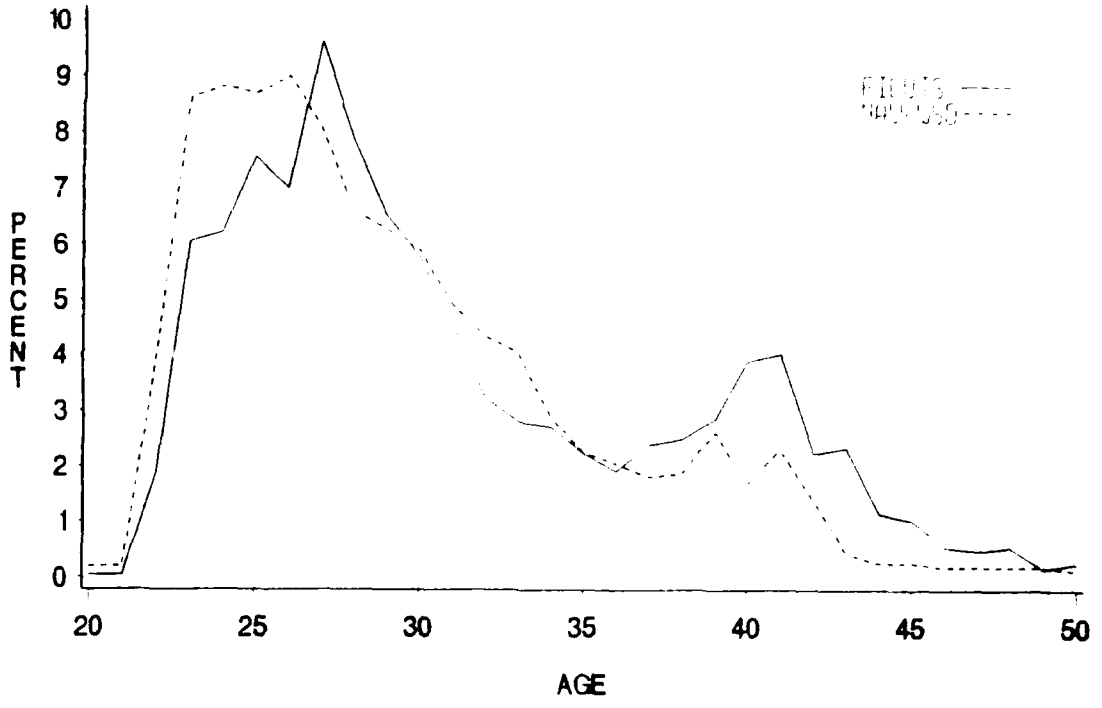

Figure 2. Distribution of ages in pilots (N=3226) and Nav/WSO (N=1634) from our sample as of 15 June 1988.

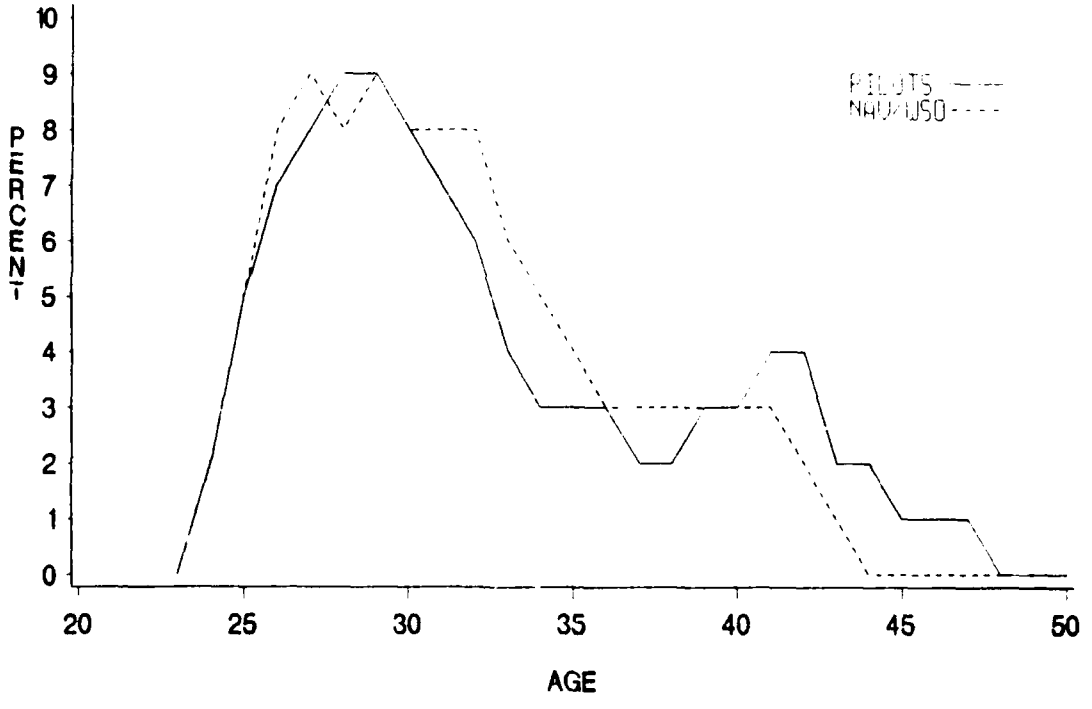

Figure 3. Distribution of ages in pilots (N=18,026) and Nav/WSO (N=6237) in the total USAF population as of 31 December 1988. (Sources are USAFMPC, Randolph AFB, Texas, and USAFSAM/NG, Brooks AFB, Texas.)

age ..., the sample data are remarkably similar to the population data. The percentages of pilots and Nav/WSO in our sample who wear spectacles are grouped by age and shown in Figure 4.

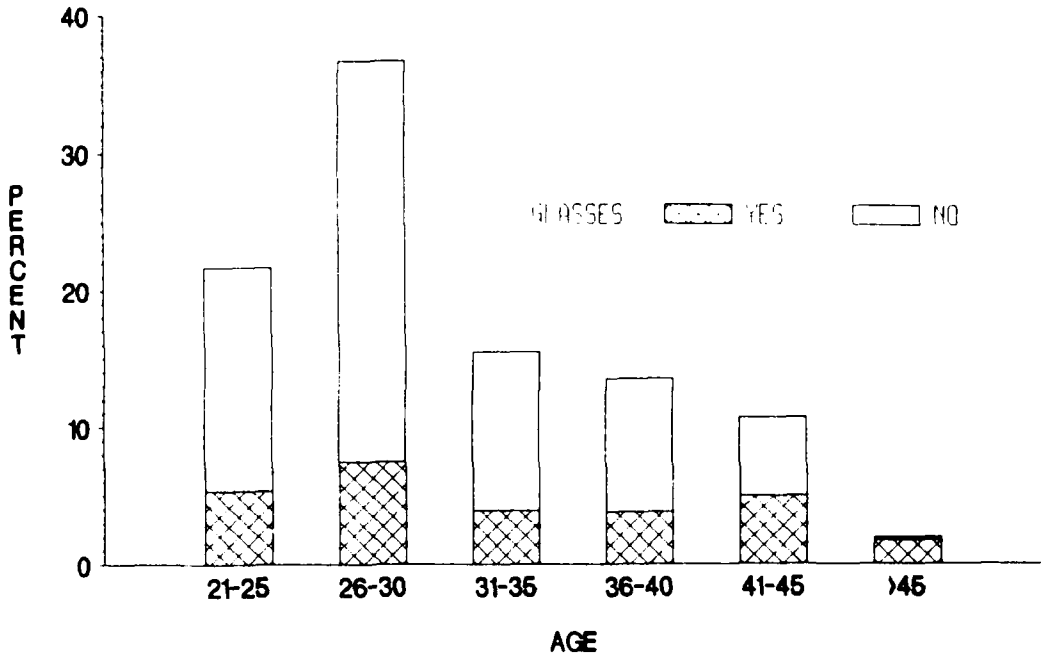

Figure 4a. Incidence of spectacle wear in pilots by age group and percentage of pilots in each age group.

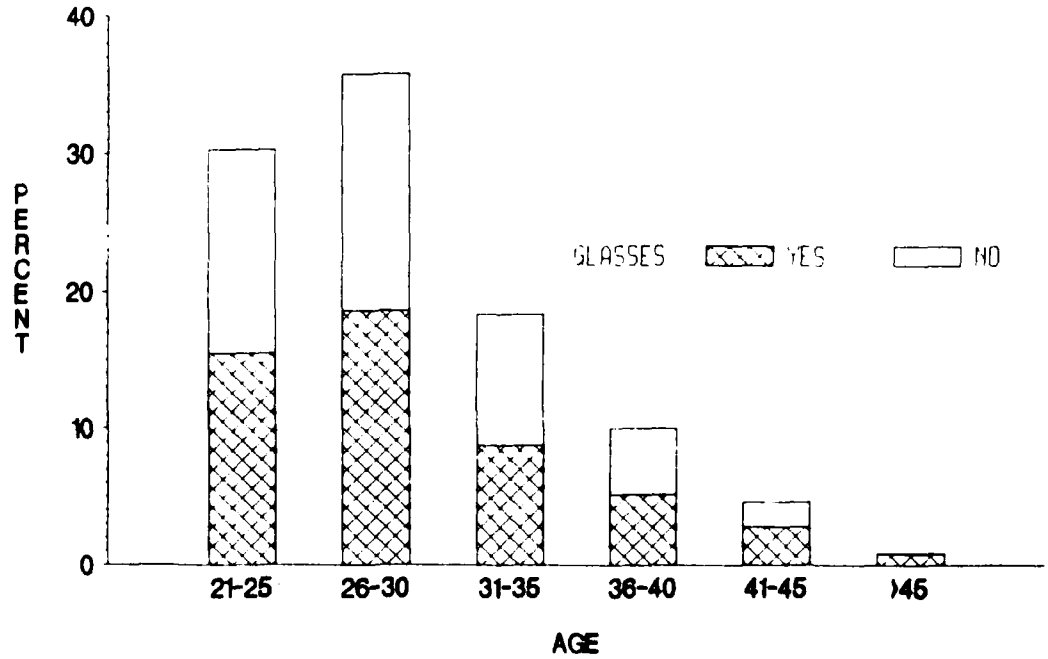

Figure 4b. Incidence of spectacle wear in Nav/WSO by age group and percentage of Nav/WSO in each age group.

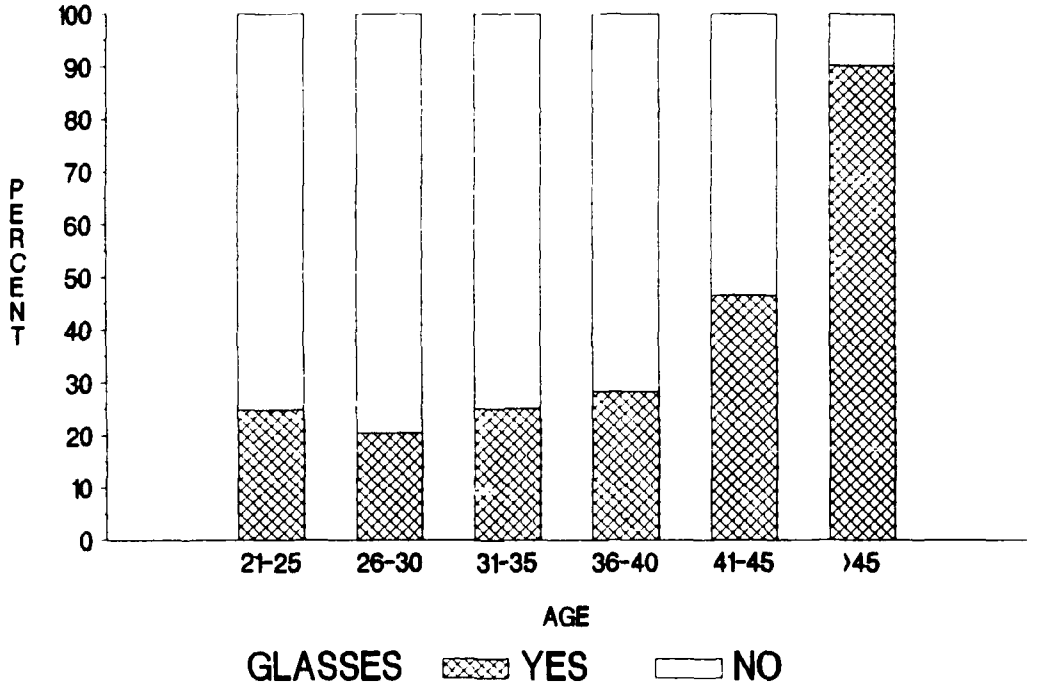

Figure 4c. Same data as in Figure 4a with incidence of spectacle wear in each age group normalized to 100%.

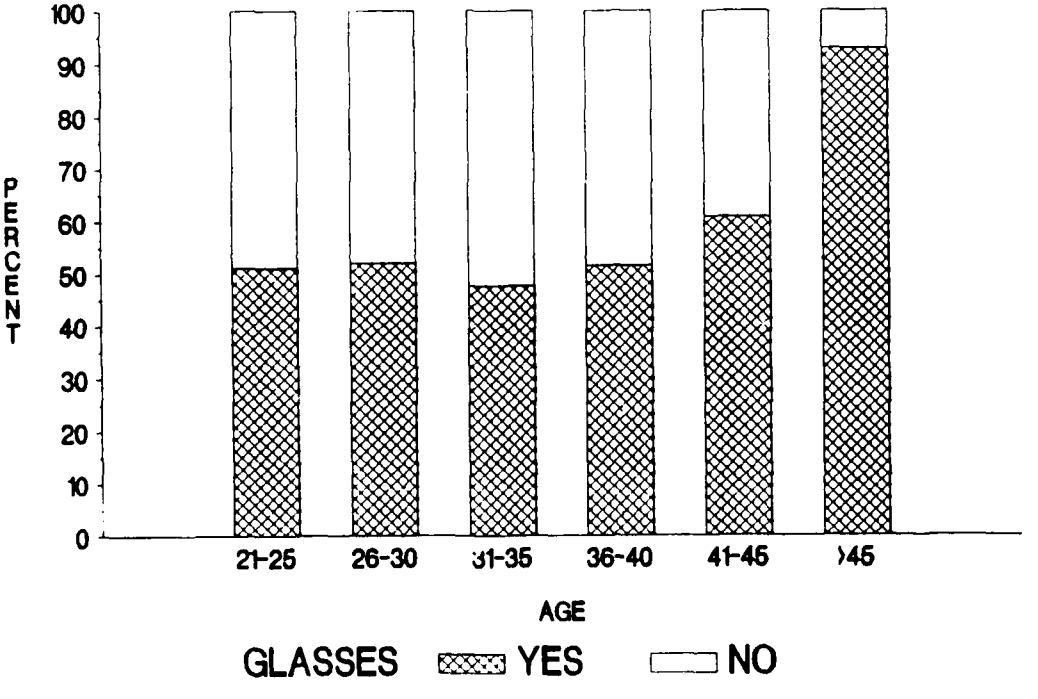

Figure 4d. Same data as in Figure 4b with incidence of spectacle wear in each age group normalized to 100%.

Current Refractive Data

The distribution of current refractive data for spectacle-wearing pilots and Nav/WSO is plotted in Figure 5, and for other aircrew in Figure 6. All data were taken from the manifest examination that was most current; refractive error was represented by the spherical equivalent value (SPEQ = sphere power plus 1/2 the cylinder). Only data from the right eye were used because comparison of right and left eyes revealed no significant differences in SPEQ.

The data show that 80.5%, 91.7%, and 82.5%, respectively, of spectacle-wearing pilots, Nav/WSO, and other aircrew members are myopic, i.e., have greater than or equal to -0.12 D of SPEQ myopic refractive error (Table A-2). The mean values in diopters (D) were -0.60 D for Pilots, -1.30 D for Nav/WSO, and -1.60 D for Others.

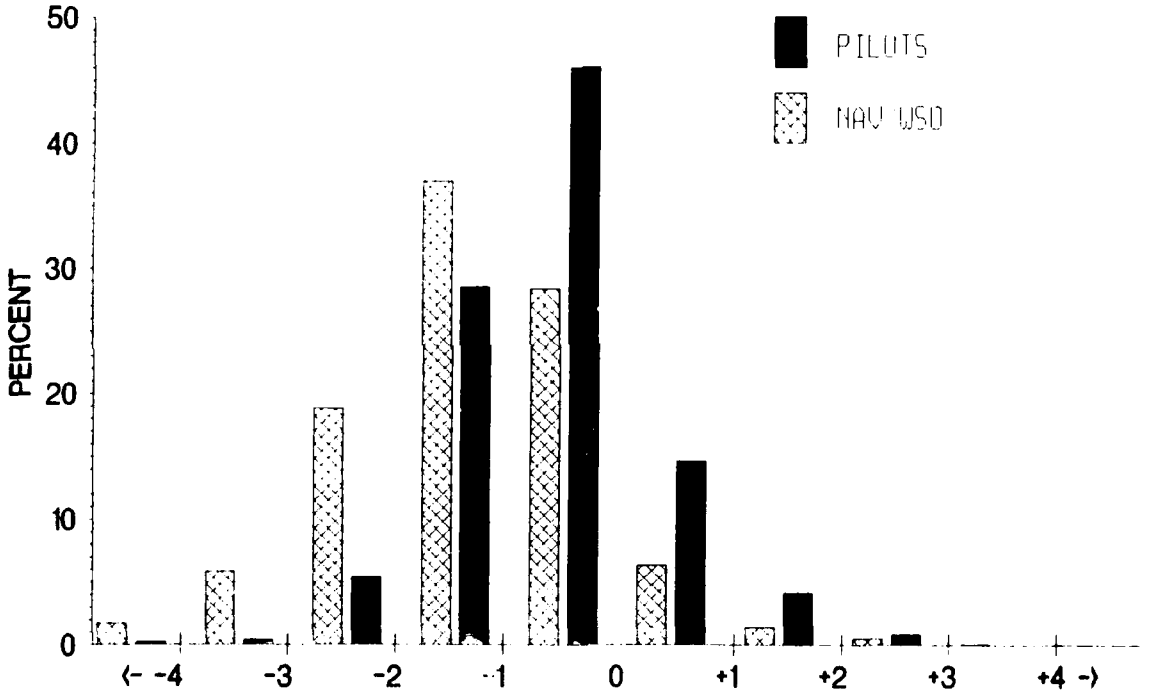

Figure 5. Distribution of SPEQ refractive error for spectacle-wearing pilots (N=885) and Nav/WSO (N=842) from their most current eye examinations. (Data are from manifest examinations.)

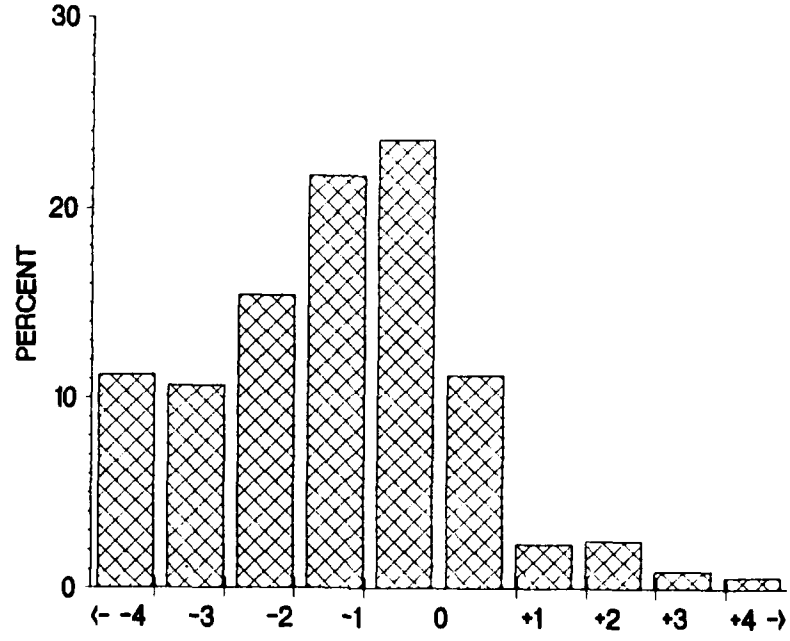

Figure 6. Distribution of SPEQ refractive error for spectacle-wearing Other aircrew members (N=687) from their most current eye examinations. (*Data are from manifest examinations.*)

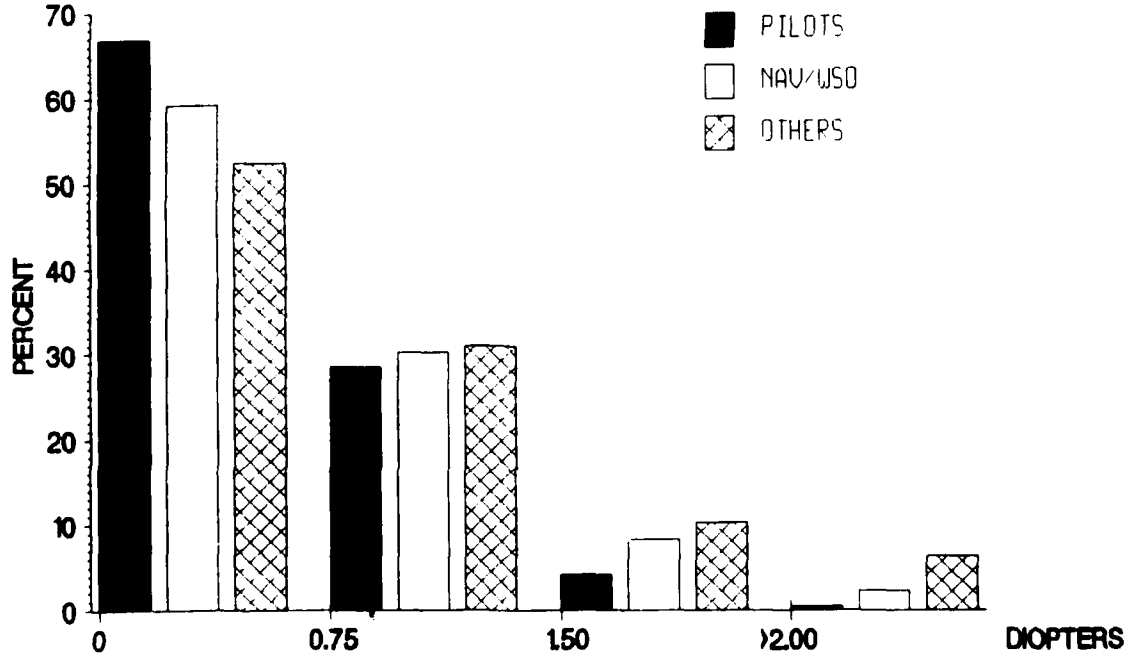

Figure 7. Distribution of astigmatism in spectacle-wearing pilots (N=885), Nav/WSO (N=842), and Others (N=687).

The frequency of astigmatic errors among aircrew members who wear spectacles is displayed in Figure 7. It can be extrapolated from this data that 33.1% of Pilots, 40.8% of Nav/WSO, and 47.5% of Others have astigmatism of 0.75 D or more (Table A-3). This amount of astigmatism has clinical and visual significance, and will be addressed in the Discussion section.

Initial Refractive Data

The SPEQ refractive data for pilots and Nav/WSO at the time they entered the Air Force on EAD are shown in Figure 8. The data were taken from their initial cycloplegic examinations which are required at entry per Air Force Regulation (AFR) 160-43. The mean values were +0.20 D for Pilots; -0.30 D for Nav/WSO; and -0.60 D for Others. It should be pointed out that this figure includes all pilots and all navigators, whereas the current SPEQ data in Figure 5 includes only spectacle-wearing aircrew members.

It is obvious that Nav/WSO were more frequently myopic and had higher levels of myopia than pilots (Table A-4). Until recently, the maximum allowable myopia for acceptance into UPT was -0.25 D, and for acceptance into UNT was -2.75 D for candidates age 21 years or older. For candidates less than 21 years old, UPT limits were plano and UNT limits were -1.50 D (5).

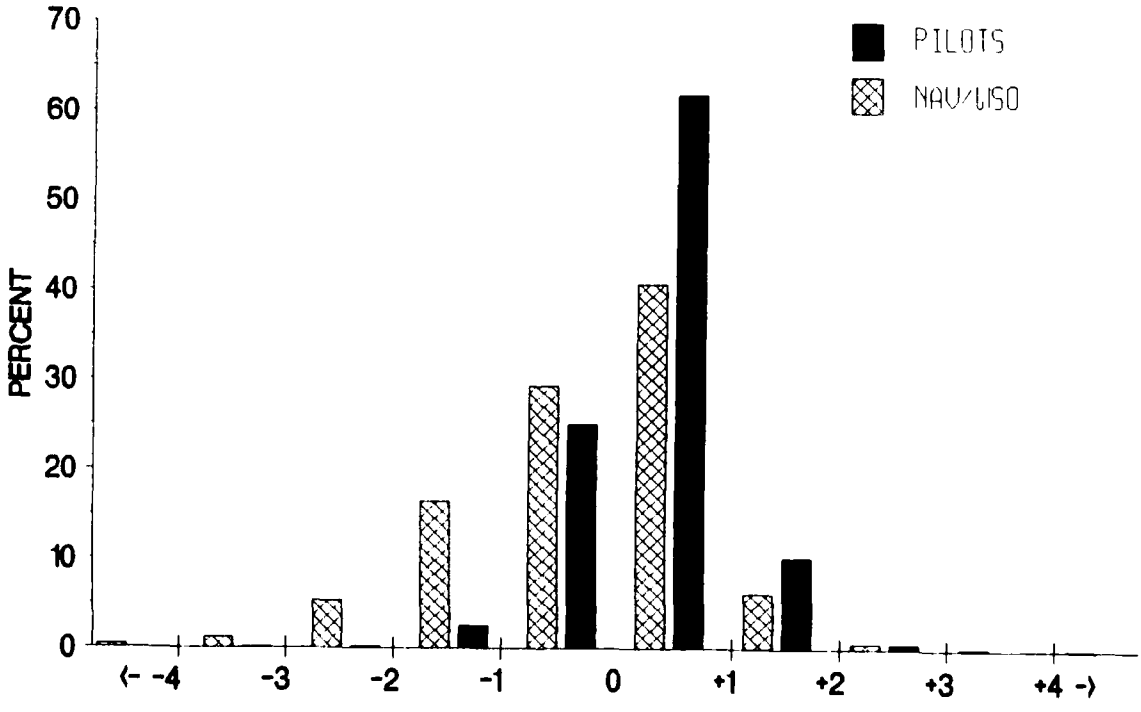

Figure 8. Distribution of SPEQ refractive error for all pilots (N=3226) and all Nav/WSO (N=1634) at time of their entry on EAD. (Data are from cycloplegic examinations.)

Changes Over Time

The percentages of pilots and Nav/WSO required to wear spectacles at entry on EAD, at entry into UPT or UNT, and at the present time are compared in Table 3. Note the almost 5-fold increase among pilots required to wear spectacles from their entry on EAD to the present time (5.7% to 27.4%). The change in percentages for Nav/WSO was not nearly as dramatic (39.7% to 51.5%).

TABLE 3. PILOTS AND NAVIGATORS REQUIRED TO WEAR SPECTACLES AT MAJOR MILESTONES

Milestones	Pilots		Nav/WSO	
	Ns/Nt	%	Ns/Nt	%
Entry on EAD	180/3143	5.7	631/1589	39.7
Entry into UPT/UNT	446/3000	14.9	705/1569	44.9
Present time	885/3226	27.4	842/1634	51.5

Ns = number required to wear spectacles
Nt = total number in survey
% = percentage of spectacle wearers out of total number of pilots or navigators

The initial refractive data are compared to the current refractive data for spectacle-wearing pilots and Nav/WSO in Figures 9 and 10. These figures trace the shift to myopia over time in USAF aircrew. It is obvious that most of the pilots who now wear spectacles did not wear them when they entered the Air Force.

Spectacle Wear by Mode of Entry

Spectacle wear in pilots, segregated by mode of entry into the Air Force, is presented in Table 4. Those pilots who entered via the USAFA demonstrate the largest incremental increase in spectacle wear from time of entry on EAD to the time they started UPT (8.6% to 33.3%). This trend was not found in similar groups who entered on EAD from AFROTC (4.8% to 7.7%) or OTS (4.7% to 7.5%). It also appears that the percentage of spectacle wearers was greatest for USAFA pilots at all three stages compared with AFROTC or OTS pilots. Presently, USAFA graduates have approximately a 14% higher incidence of spectacle wear than AFROTC or OTS pilots.

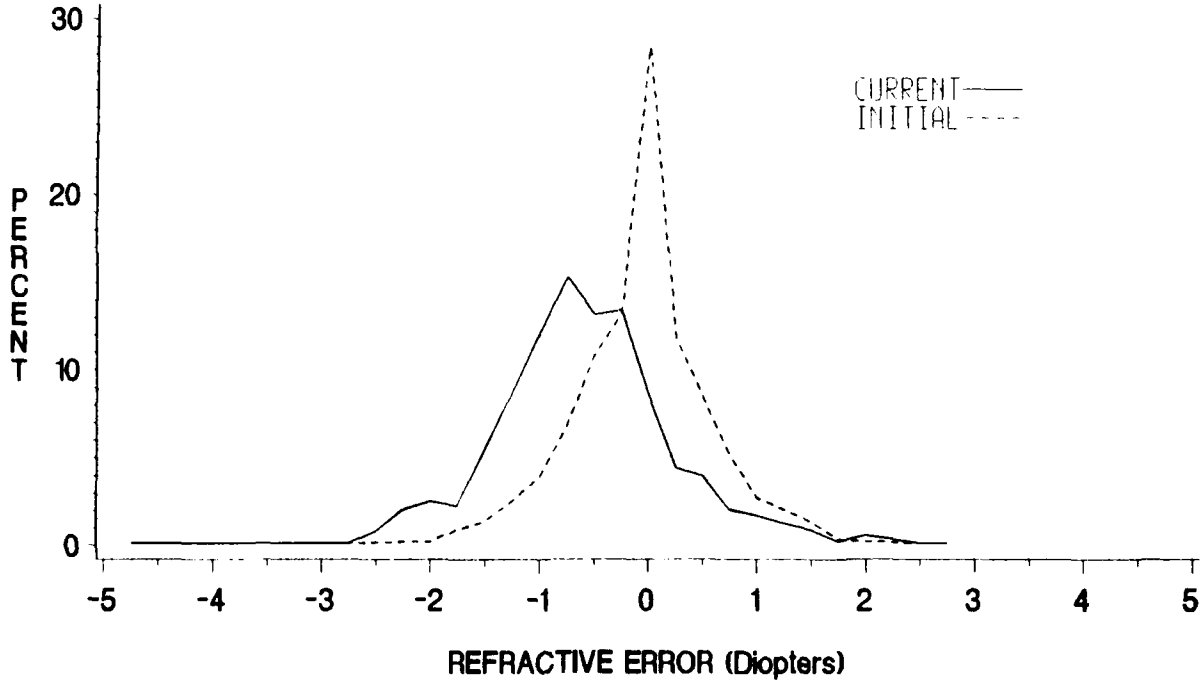

Figure 9. Distribution of SPEQ refractive error for only those pilots (N=885) who currently wear spectacles from their entry on EAD and most current eye examinations.

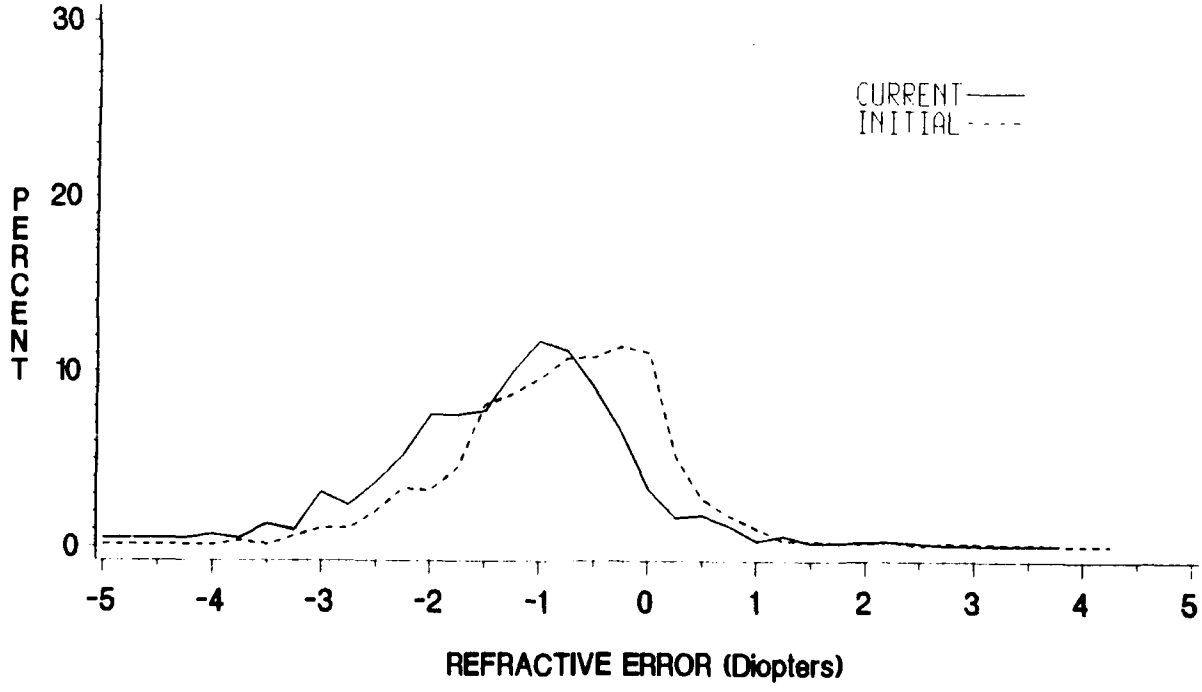

Figure 10. Distribution of SPEQ refractive error for only those Nav/WSO (N=842) who currently wear spectacles from their initial entry on EAD and most current eye examinations.

TABLE 4. PILOTS* BY MODE OF ENTRY WHO WERE REQUIRED TO WEAR SPECTACLES AT MAJOR MILESTONES

Milestone	USAFA		AFROTC		OTS	
	Ns/Nt	%	Ns/Nt	%	Ns/Nt	%
Entry on EAD	74/861	8.6	57/1193	4.8	46/987	4.7
Entry into UPT	286/860	33.3	85/1109	7.7	69/925	7.5
At present	330/876	37.7	276/1203	22.9	244/1010	24.2

Ns = number required to wear spectacles
Nt = total number in survey
% = percentage of spectacle wearers out of total number of pilots

*Pilots who entered on EAD from modes other than USAFA, AFROTC or OTS were not included.

DISCUSSION

Prevalence of Spectacle Wear

The most significant finding of this study is that 27.4% of pilots, 51.5% of Nav/WSO, and 40.2% of other aircrew members are required to wear spectacles when flying. Applying these percentages to the entire USAF aircrew population, as listed at the bottom of Table 2, an estimated 7,015 Pilots, 5,450 Nav/WSO, and 4,796 Others must wear spectacles in flight. Thus, a total of 17,261 USAF aircrew members require spectacle correction. Recall that this data applies only to active flyers. Aircrew members assigned to duties other than active flying, even though they may receive flight pay and must remain flight qualified, were excluded. Including nonactive flyers would surely increase the number of spectacle-wearing aircrew members, because many nonactive flyers are senior officers at or near the age of presbyopia. In fact, if the nonactive flyers were included into the age data, 28.2% of pilots and 22.8% of Nav/WSO would be in the 40-year or older group. The prevalence of spectacle wear in the USAF flying population is obviously extensive.

A considerable number of aircrew members, especially pilots, wear bifocals. Wearing bifocals in the aerospace environment can create problems, e.g., the F-16 pilot with his head tilted back in a 30-degree reclined seat, or the helicopter pilot who must look down and outside while the aircraft is hovering. The presbyopic pilot is faced with some unique challenges (4).

Engineers designing flight life-support equipment must consider the fact that a large number of aircrew members wear spectacles. They must learn to incorporate spectacle compatibility into life-support equipment early in the design process. The previous practice of fielding new systems and then trying

to adapt them retroactively to permit spectacle wear is neither efficient nor cost effective.

Entrance visual standards for aircrew may need to be re-evaluated. Should we continue to allow so many spectacle wearers into USAF flying training programs when they will be constrained by the nuisance of wearing eyeglasses? The afore-mentioned spectacle problems of fogging, weight, restricted field of view, comfort, displacement, and reflections at night are potentially dangerous. On the other hand, it is difficult to believe that corrected refractive error poses any serious problem in flying, because spectacle-wearing aircrew members have performed the mission without objective detriment (2,3,10). Spectacle incompatibility with flight gear, however, is a potential performance problem, especially for the single-seat fighter pilot with a complex, task-intensive job. Accordingly, spectacle wear might be a criterion in initial aircraft assignment, i.e., spectacle wearers assigned to multiengine aircraft (bombers or tankers), and nonspectacle wearers assigned to fighter aircraft.

It is interesting, as Table 1 reveals, that TAC has about the same percentage of pilots requiring spectacles as SAC, MAC, or ATC (the differences among MAJCOMs are not statistically significant with Chi-square analysis at the $p = .05$ level). Obviously, spectacle wear is not currently a consideration when making MAJCOM and/or aircraft assignments (14).

The statistical data in this report regarding the prevalence of spectacle wear by aircrew members are important in planning optical logistic support. The military optical laboratories must be able to project workloads and manning levels and maintain an adequate stock of frames and lenses. In addition, the data are important for USAFSAM in its attempt to develop an improved aircrew spectacle frame for fighter pilots that is more compatible with life-support equipment and to provide optical support for spectacle-wearing aircrew members using night vision goggles.

Finally, a new policy is being implemented that allows some aircrew members to wear soft contact lenses instead of spectacles. Statistics on the prevalence and magnitude of refractive errors in USAF aircrew are essential to plan logistical support, professional time requirements, and budgets for lenses and supplies. When aircrew wear of soft contact lenses is implemented, commanders must anticipate the expected incidence of ocular complications and DNIF (duties not including flying) time in their squadrons. Otherwise, mission effectiveness rates may decline.

Visual Acuity

The visual acuity data for pilots and navigators suggests that some flyers wear spectacles despite having 20/20 or better uncorrected distance visual acuity. Extrapolating from the data, 20.2% of pilots and 45.1% of Nav/WSO have worse than 20/20 visual acuity; however, over 27% of pilots and 51% of Nav/WSO wear spectacles (Table 1). These differences are probably attributable to aircrew members with reduced near vision only (i.e., presbyopia with normal distance vision), monocular problems with 20/20 in the better eye, or low myopic astigmatism that does not decrease visual acuity to worse than 20/20. Furthermore, visual acuity was found to be poorly correlated with refractive error

in spectacle-wearing pilots and Nav/WSO combined (R=0.63, Pearson correlation coefficient). This data may reflect inconsistencies in visual acuity measurements obtained on routine vision screening. Also, 20/20 uncorrected visual acuity in some flyers may represent a drop in vision from a previous 20/15 or even 20/10 (9). An aircrew member who formerly had 20/10 visual acuity may pass the vision screening, but may be unhappy with only 20/20 vision.

Age

It is readily apparent that the ages of aircrew members in our sample (Fig. 2) were quite representative of the USAF flying population data (Fig. 3), the only exception being that the sample data included some younger student pilots and Nav/WSO. As expected, the data in Figure 4 show that the prevalence of spectacle wear for pilots and Nav/WSO increases with age, especially past age 40. However, when we looked at the relationship between age and refractive error (Appendix B), no correlation was found. This is somewhat contrary to the concept of myopic progression and probably is due to the fact that most refractive error changes in aviators occur before UPT or UNT, or during the first five years after training (7,8).

Current Refractive Data

Myopia is the predominant refractive error in spectacle-wearing aircrew members. A definite skew toward myopia (minus refractive error) is shown in Figure 5, which is quite similar to the data from Provines et al. (11). In general, higher myopic corrections occur in Nav/WSO and Others, reflecting their less stringent visual standards for entry (5).

Categorizing refractive error by the amount of astigmatism is also important. Astigmatism equal to or greater than 0.75 D is visually significant when fitting soft contact lenses, when wearing night-vision goggles without spectacles, and when fabricating SPEQ spectacle lenses on the battlefield. Provines et al. (12) found that 28.4% of spectacle-wearing pilots and navigators combined had 0.75 D or more of astigmatism, which is slightly less than our data of 33.1% in pilots and 40.8% in Nav/WSO. As an aside, we looked at the correlation between the amount of astigmatism (cylinder) and the magnitude of spherical refractive error. These two parameters were found to be independent (Appendix C), but our sample is obviously biased because entry standards restrict the amount of astigmatism (5).

Initial Refractive Data

The initial SPEQ refractive error for all pilots and navigators at entry on EAD is also similar to that found earlier in other studies (7,8,10,11). Our data for pilots and Nav/WSO show a tight clustering (leptokurtosis) around emmetropia with a definite hyperopic skew, although Nav/WSO have a myopic tail. Extrapolating from Figure 8, only 8.7% of pilots had more than -0.25 D of myopia at the time of entry on EAD. The visual standards for UPT, however, require each candidate to have no more than -0.25 D of myopia. Thus, at least 8.7% of pilot candidates had to be given waivers for excessive myopia at the

time they entered on EAD. Somewhat contradictory information is shown in Table 3, because only 5.7% of pilots were actually required to wear spectacles when they entered on EAD. This data may reflect problems in the initial entry physical examination process. Although waivers for myopia were being granted at that time, spectacles were not prescribed, when indicated, for some pilot candidates with low myopia.

Changes Over Time

There are dramatic and consistent increases in the percentages of pilots and navigators required to wear spectacles over the course of their USAF careers. Of those pilots who currently wear spectacles, only 17.6% wore them at the time of initial entry on EAD. There is also a large change in the data for pilots from entry on EAD to UPT entry in spite of the fact that the elapsed time from initial entry on EAD to flight training is only 1-3 years for most pilots. The most probable explanation is that this is the time of life when myopic changes often appear (i.e., late teens or early 20s - the college years) (1,4,6,7,8,13). The move toward myopia in pilots is also very obvious (Fig. 4). The implications of this trend for predictive value and setting visual standards will be addressed in another paper.

Spectacle Wear by Mode of Entry

Pilots who enter on EAD from the USAFA have greater incidences of spectacle wear at each milestone than pilots from AFROTC or OTS. The refractive changes which occur between entry into the USAFA and entry into UPT, approximately 3 years' time, is especially dramatic (8.6% to 33.3%). O'Neal and Connon, who earlier noted this myopic shift at the USAFA (7,8), found that 25% of entering emmetropes (cycloplegic refraction SPEQ of +0.12 D to -0.12 D) needed spectacles at graduation. They concluded that emmetropic 17- to 21-year-old cadets were not immune from developing myopia, particularly during an intensive educational program.

Why were larger changes found in pilots who entered on EAD via the USAFA as compared to other modes of entry? A plausible explanation is that cadets at the USAFA are younger than those who enter on EAD via OTS and AFROTC, and more time elapses between their entry and training. Also, waivers were given more liberally to USAFA cadets, especially at the time they entered UPT; therefore, those with myopic shifts were still retained as pilots.

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APPENDIX A

VISUAL EXAMINATION TABLES

TABLE A-1. UNCORRECTED VISUAL ACUITY OF PILOTS AND NAVIGATORS

Current Examination	Pilots		Nav/WSO	
Visual acuity	N	%	N	%
20/20 or better	2575	79.8	897	54.9
20/25 & 20/30	259	8.0	152	9.3
20/40 & 20/50	203	6.3	174	10.6
20/60 & 20/80	118	3.7	175	10.7
20/100 or worse	71	2.2	237	14.5
Total	3226	100.0	1635	100.0

N = Number of aircrew members
% = percentage of column total

TABLE A-2. REFRACTIVE ERROR IN SPECTACLE-WEARING AIRCREW MEMBERS

Current Examination	Pilots		Nav/WSO		Others	
SPEQ	N	%	N	%	N	%
+4.00 or more	0	0.0	0	0.0	4	0.6
+3.00 to +3.88	0	0.0	1	0.1	6	0.9
+2.00 to +2.88	7	0.8	4	0.5	17	2.5
+1.00 to +1.88	36	4.1	12	1.4	16	2.3
plano to +0.88	129	14.6	53	6.3	77	11.2
-0.12 to -0.88	407	46.0	239	28.4	162	23.6
-1.00 to -1.88	252	28.5	311	37.0	149	21.7
-2.00 to -2.88	48	5.4	158	18.8	106	15.4
-3.00 to -3.88	4	0.4	49	5.8	73	10.6
-4.00 or more	2	0.2	14	1.7	77	11.2
Total	885	100.0	841	100.0	687	100.0

SPEQ = spherical equivalent in diopters
N = Number of aircrew members
% = percentage of total

TABLE A-3. ASTIGMATISM IN SPECTACLE-WEARING AIRCREW MEMBERS

Astigmatism	Pilots		Nav/WSO		Others	
Diopters	N	%	N	%	N	%
plano to 0.50	592	66.9	498	59.2	361	52.5
0.75 to 1.25	252	28.5	254	30.2	213	31.0
1.50 to 2.00	37	4.2	70	8.3	70	10.2
more than 2.00	4	0.4	19	2.3	43	6.3
Total	885	100.0	841	100.0	687	100.0

N = Number of aircrew members
% = percentage of total

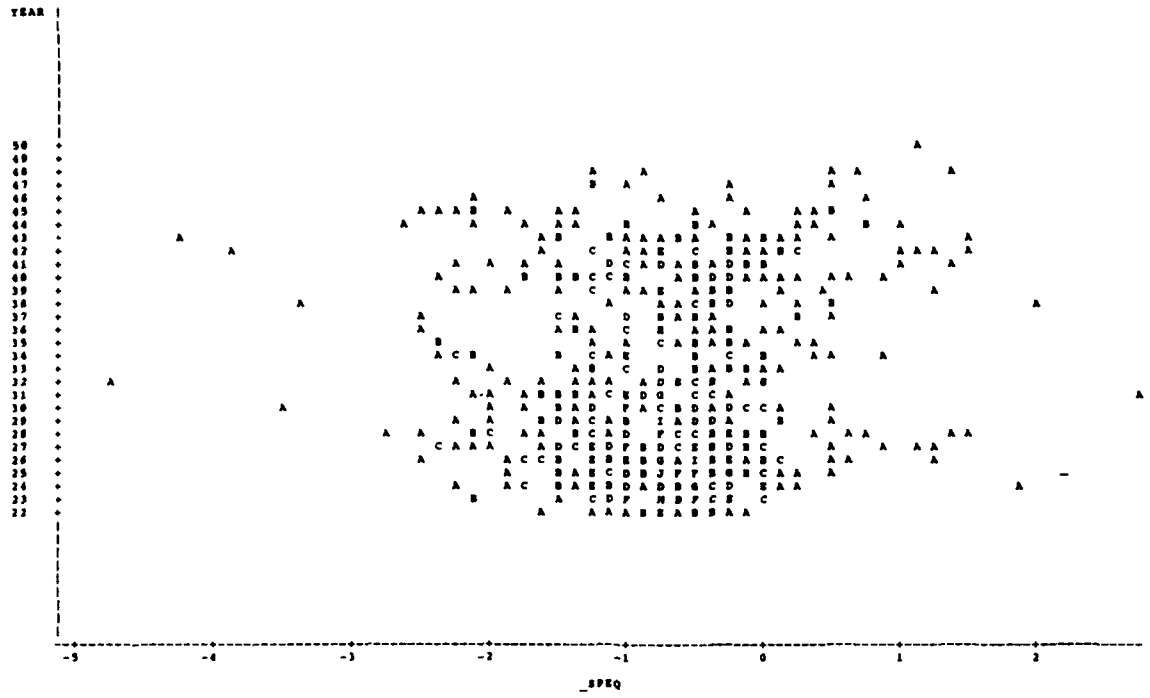
TABLE A-4. REFRACTIVE ERROR IN ALL PILOTS AND NAV/WSO UPON INITIAL ENTRY INTO THE U.S. AIR FORCE

Entry Examination	Pilots		Nav/WSO	
SPEQ	N	%	N	%
+4.00 or more	0	0.0	1	0.1
+3.00 to +3.88	0	0.0	1	0.1
+2.00 to +2.88	12	0.4	11	0.7
+1.00 to +1.88	322	10.1	99	6.2
+0.12 to +0.88	1562	49.2	518	32.2
plano to -0.25	1003	31.6	405	25.2
-0.38 to -0.88	192	6.0	202	12.6
-1.00 to -1.88	79	2.5	264	16.4
-2.00 to -2.88	4	0.1	84	5.2
-3.00 to -3.88	2	0.1	18	1.1
-4.00 or more	0	0.0	4	0.2
Total	3176	100.0	1607	100.0

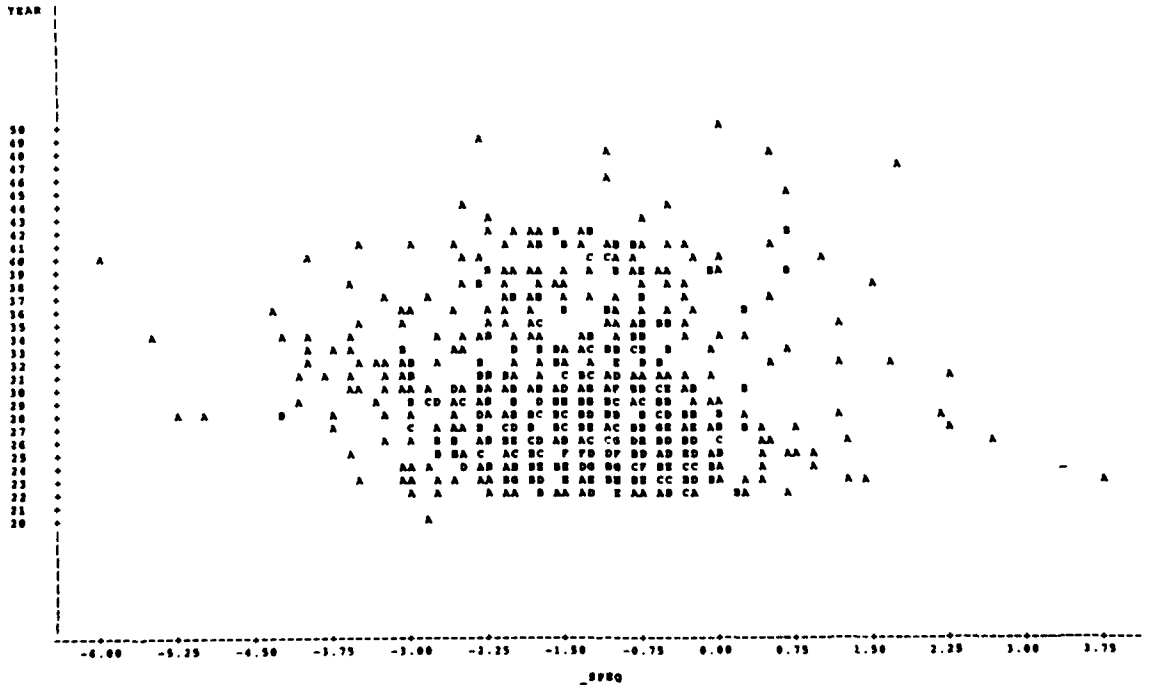
SPEQ = spherical equivalent in diopters
N = Number of aircrew members
% = percentage of total

APPENDIX B

AGE/REFRACTIVE DATA COMPARISON



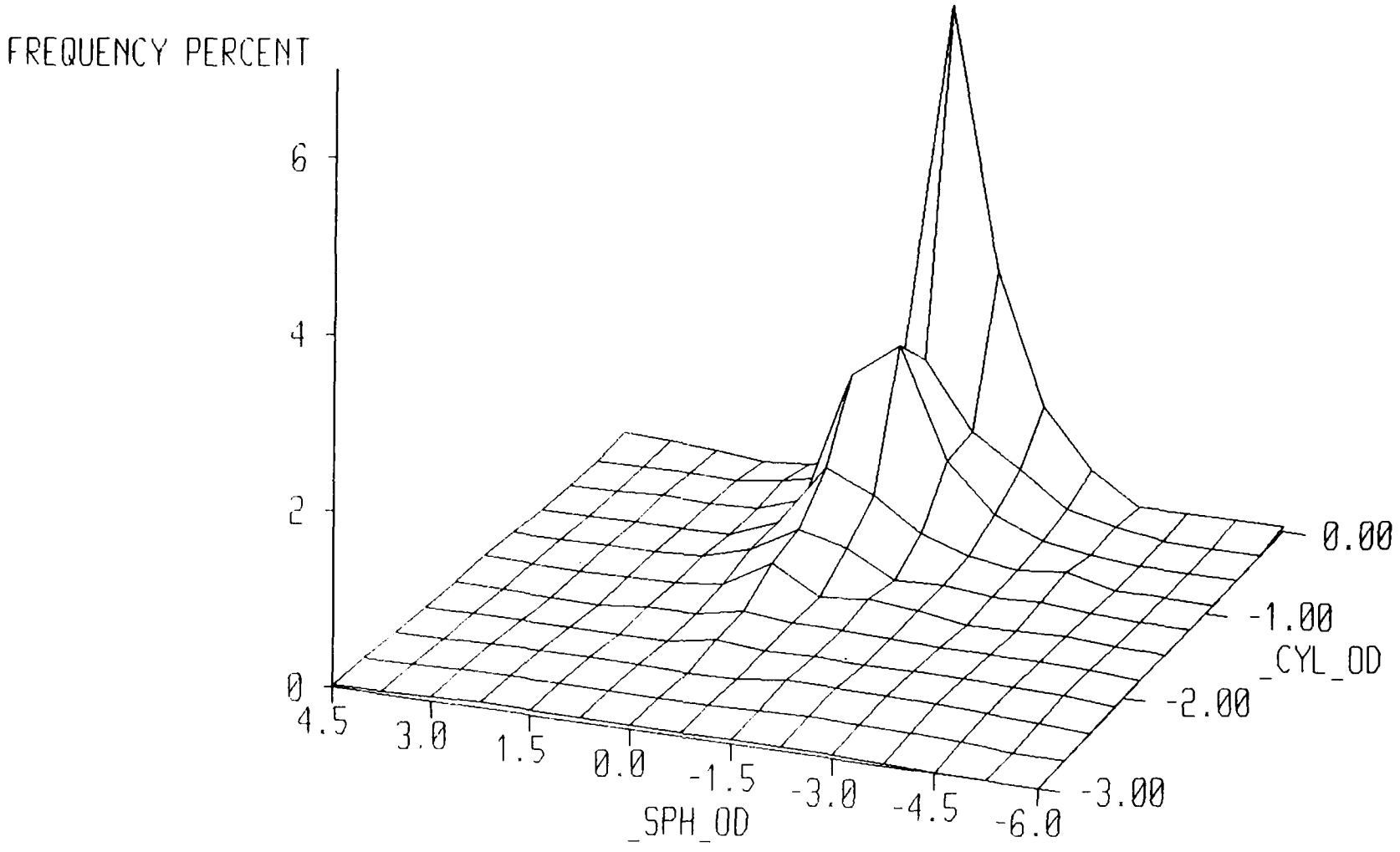
B-1. Plot of age versus current refractive error in pilots.



B-2. Plot of age versus current refractive error in Nav/WSO.

APPENDIX C

ASTIGMATISM/SPHERICAL REFRACTIVE ERROR



C. Distribution of cylindrical and spherical measurements for pilots and Nav/WSO.

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